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Calculating Filter Capacitor Values for Computer Power Supplies

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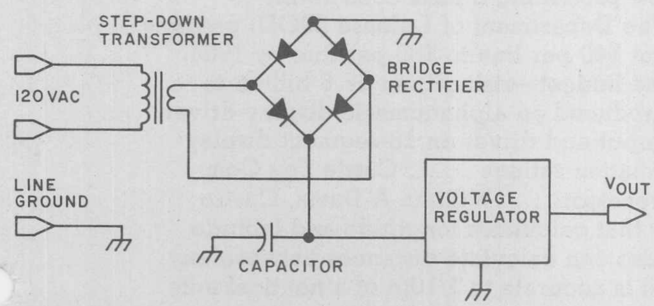

Figure 1: *Schematic diagram of a typical power supply circuit containing a step-down transformer, a full-wave bridge rectifier, a filter capacitor, and an integrated circuit voltage regulator.*

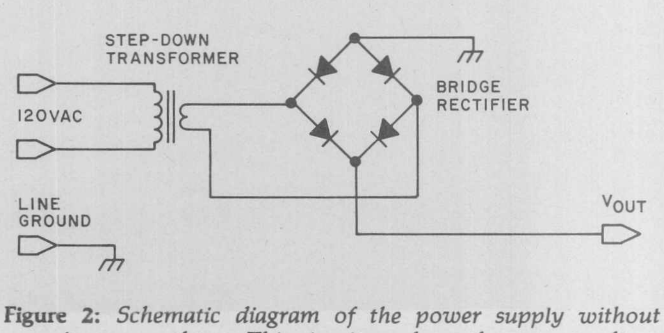

Figure 2: *Schematic diagram of the power supply without capacitor or regulator. This circuit produces the output voltage waveform shown in figure 3.*

Typically there are four functional elements in a homebrew computer power supply. These elements are: the transformer, full-wave bridge rectifier, filter capacitor, and one or more integrated circuit voltage regulators as shown in figure 1. Experience has shown that most homebrewers have little difficulty in choosing any of the components, except when it comes to finding the value of the filter capacitor. Then they must resort to methods of multiple approximation, charts and graphs, or the better known and widely used method of trial and error. The following information will simplify the process of finding the smallest value of capacitance that will work in the circuit.

Equation 1 gives the formula used to calculate the capacitor value:

$$C_{min} = \frac{i_{max}\left[\dfrac{1}{4f} + \dfrac{1}{2\pi f}\arcsin\left(\dfrac{V_{min}}{V_{max}}\right)\right]}{V_{max} - V_{min}} \qquad (1)$$

where:
f = the power-line frequency in hertz
V_{max} = the value of the peak positive voltage applied to the capacitor under the worst conditions (eg: highest operating temperature, greatest current, lowest power-line voltage)
V_{min} = the absolute minimum voltage allowable at the input of the voltage regulator

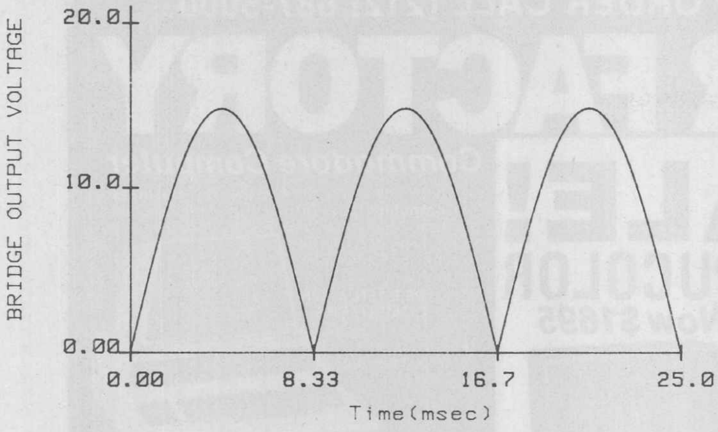

Figure 3: *The voltage waveform produced by the circuit of figure 2. The output of the rectifier stage of the supply is a pulsating current with only positive polarity.*

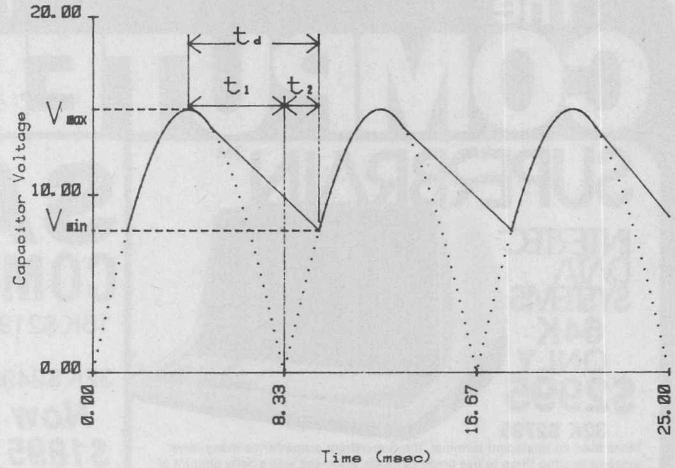

Figure 4: *Addition of a capacitor to the circuit has this effect on the output waveform. The capacitor smooths the humps in the waveform; an almost constant DC voltage with a small fluctuation (ripple) is presented to the voltage regulator stage of the power supply.*

Figures 3 and 4 were produced on a Hewlett-Packard 9872A plotter controlled by a Hewlett-Packard 9845A desk-top computer.

i_{max} = the maximum average current drawn during any one-quarter segment of a power-line cycle

C_{min} = the capacitance in farads; this is the minimum value that will meet the V_{min} specification

Those who are familiar with the above symbols and the effects of the circuit elements on the corresponding component values need read no further. However, anyone wishing to have a better description of V_{max}, V_{min}, i_{max}, and how to choose appropriate values, should read on.

Where the Formula Comes From

If the capacitor and voltage regulator are removed from the power supply in figure 1, the circuit of figure 2 remains. The circuit has an output-voltage waveform resembling that shown in figure 3. The waveform produced emulates the absolute value function of a sine curve. With the capacitor and regulator replaced so that the circuit is once again as shown in figure 1, the voltage across the capacitor will appear as shown in figure 4. Thus the capacitor has a smoothing-out effect on the waveform in figure 3. As shown in figure 4, the voltage across the capacitor follows the waveform of figure 3 while charging. When discharging, the voltage falls down to a value V_{min}. This value is the lowest voltage permissible as input into the voltage regulator, such that the regulator can still function properly. V_{min} should typically be about 2 V greater than the regulator-ouput voltage.

The capacitor formula is derived using the definition of capacitance found in almost any book on network theory:

$$i = C\frac{dv(t)}{dt} \tag{2}$$

where:
i = current in amperes
v = voltage in volts
t = time in seconds

and: C = capacitance in farads

This equation may be simplified by assuming that the current, i, is constant. This assumed value of current is the sum of currents drawn by the computer and the voltage regulator. If the current is not constant, it must be equal to the maximum *average* current drawn during any one-quarter segment of a power-line cycle. Once the current i is chosen and assumed constant, equation 2 can be simplified to give equation 3:

$$C = \frac{i_{max}\, t_d}{V_r} \tag{3}$$

where:
i_{max} = the maximum average current discharging the capacitor during any one-quarter segment of a power-line cycle,
t_d = the capacitor discharge time (see figure 4), and
V_r = the ripple voltage, $V_{max} - V_{min}$

The time t_d over which the capacitor discharges can be broken into two parts, t_1 and t_2, as shown in figure 4. The time t_1 is the interval in which the sine waveform is decreasing, and is equal to one-fourth of the power-line frequency period. The time t_2 is the time required for the sine wave to go from 0 to V_{min}. For a power-line frequency of f, the total capacitor discharge time, t_d, is given by equation 4:

$$t_d = t_1 + t_2$$

$$t_1 = \frac{1}{4f}$$

$$t_2 = \frac{1}{2\pi f}\arcsin\left(\frac{V_{min}}{V_{max}}\right)$$

or:

$$t_d = \frac{1}{4f} + \frac{1}{2\pi f} \arcsin\left(\frac{V_{min}}{V_{max}}\right) \qquad (4)$$

After substituting for t_d and V_r in equation 3, the final cookbook formula given in equation 1 is obtained.

Design Example

As an example, suppose that a microcomputer board requires a 5 V supply to deliver 3 A. Assume that V_{max} under the worst-case conditions is found to be 14.8 V and that the integrated circuit voltage regulator requirements set V_{min} to be 8.0 V. (The values for V_{max}, V_{min}, and i_{max} were taken from chapter 8, page 9 of the *Voltage Regulator Handbook* by National Semiconductor. The value calculated in the handbook was 2400 μF.)

$$C_{min} = \frac{3\text{ A}\left[\dfrac{1}{4(60\text{ Hz})} + \dfrac{1}{2\pi(60\text{ Hz})}\arcsin\left(\dfrac{8.0\text{ V}}{14.8\text{ V}}\right)\right]}{14.8\text{ V} - 8.0\text{ V}}$$

therefore:

$$C_{min} = 2500\mu\text{F}$$

Some Dangers to Watch Out For

In all of the discussion so far, it has been assumed that the capacitor can tolerate any ripple voltage. This is simply not so. Ripple voltages cause the capacitor to heat up inside. If the ripple voltage is too high, the capacitor can become too hot and explode. The value of V_{max} may have to be decreased to meet capacitor ripple voltage requirements. Consult the manufacturer's specifications for the capacitor's maximum ripple voltages and/or currents. Also, carefully check the tolerances for the value of the capacitor.

Also, care must be taken not to choose too high a value of V_{max}. Transformer-winding resistance, diode-voltage drops, diode capacitance, and low power-line voltage are some of the factors that must be considered when choosing the value of V_{max}. Setting V_{max} too high will result in C_{min} being too small.

Conclusion

Use of the formula is a fast and accurate method of finding filter capacitor values. Careful choice of V_{max}, V_{min}, i_{max}, and quality components will produce a power supply which will provide good performance.■

The author wishes to thank Mr Scott Eanes of Hewlett-Packard for his assistance in producing the graphs for this article.

References

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3. Hayt and Kemmerly, *Engineering Circuit Analysis*, McGraw-Hill, 1971.